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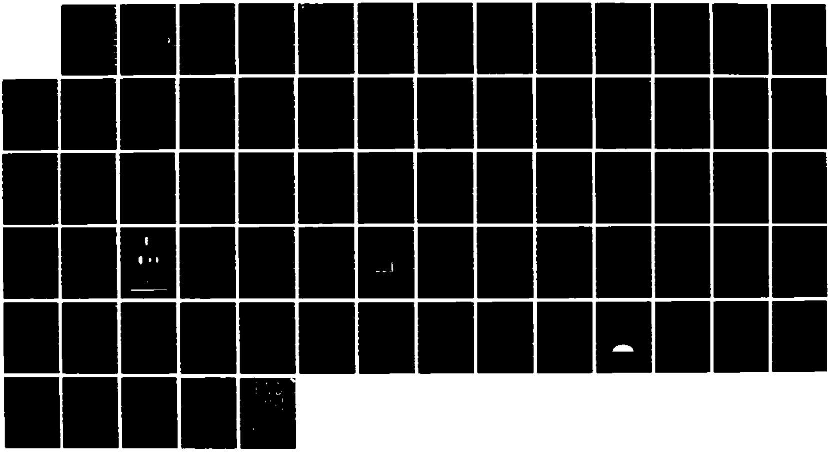

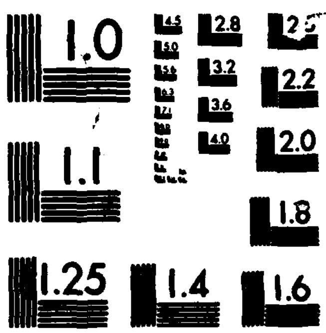

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Absolute Judgment Versus Absolute Magnitude Estimation to Convey Information Through Symbol Magnitude Changes in CRT Displays

A Thesis

submitted by

Bernard Asiu

In partial fuliillment of the requirements
for the degree of

Master of Science

in

Psychology

TUFTS UNIVERSITY
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ABSTRACT

Psychophysical scaling of symbol magnitude to convey information through CRT displays was evaluated in terms of information theory. Series of lines and ellipses each with four, eight and twelve intermediate sizes were presented to twelve subjects under absolute judgment scaling and to an additional twelve subjects under absolute magnitude estimation scaling. Under absolute judgment, information transmission is higher and equivocation and ambiguity measures are lower than those obtained under absolute magnitude estimation ($p<.01$). The difference in information transmission represents an increase of about one stimulus alternative under absolute judgment scaling and in itself does not preclude the practical application of absolute magnitude estimation to encode information. Rather it is the wide variability in median magnitude estimations that makes it difficult to reach any common ground for symbol interpretation.

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Essential to any information system is data on human abilities to detect, identify and interpret targets. A target may mean any object, pattern or marking that contains information necessary to complete system tasks. Visual codes are just one way to encode information required for task completion. Within the visual sense, information may be coded by varying color, shape, size, line length, angular orientation or target brightness just to name a few. Such codes might be used in maps, display boards, scope symbology, or warning signals. The usefulness of a particular coding method depends upon several factors including (a) the number of steps (e.g., number of colors or line lengths) that can be identified without confusion, (b) the ease with which the operator can interpret the code, (c) its affect on operator fatigue and distractability or its interference with other codes and, (d) the physical space required to present the code (Baker & Grether, 1954). Some coding methods offer better speed and accuracy depending on the task required (Van Cott & Kinkade, 1972). This might include identification, location, counting, comparison, verification or interpretation. Poorly designed or inappropriate codes decrease performance and in critical tasks may even contribute to equipment damage or personal injury.

Information may be considered quantitative, qualitative or both. Likewise, information coding methods can also be considered in the same terms. Information coded in color or shape is qualitative because colors or shapes are qualitatively different. On the other hand, codes using size, brightness or

length are quantitative because they can express the extent or magnitude of an object or process (Baker & Grether, 1954). The interest here is encoding quantitative information by correlating symbol magnitude with some actual characteristic of the object or process represented. In the air traffic control Plane View Display used to monitor air traffic separation for example, a simple relationship would be that of symbol size with aircraft speed. Such a visual code is established by setting the upper and lower scale limits and logarithmically spacing the intermediate values (Van Cott & Kinkade, 1972).

Visual codes developed in this way are interpreted by mental classification of the target symbol in relation to all possible symbols in the set. This process of absolute identification or categorization is called absolute judgment (Bainbridge, 1975). A useful indicator of symbol identification performance in absolute judgment is the amount of information transmitted. Information is frequently expressed in bits; the logarithm to the base two of the number of equally likely alternatives. The number of bits is equal to the number of two-choice discriminations required to specify a particular event from alternative ones. Unless the visual code is optimized in terms of information transmission, the operator may be either overloaded or underloaded with information. In absolute judgment of symbol magnitude, information (symbol) is input, processed and output (response). If information processing performance is high, each input will result in the desired output. By measuring the input-output relationship one can determine how much of the output variance is

due to the input and how much is due to fluctuations or noise within the system (Sheridan & Ferrell, 1974).

Given a particular stimulus continuum, the optimum number of alternatives that can be identified by absolute judgment is shown through information analysis (Attneave, 1959; Garner & Hake, 1951; Sheridan & Ferrell, 1974). The input information in a symbol magnitude code is the estimated information-per-stimulus and is expressed as:

$$H(x) = \sum p_i \log 1/p_i$$

where the subscript i refers to any particular but unspecified stimulus. The output is the estimated information-per-response and is expressed as:

$$H(y) = \sum p_j \log 1/p_j$$

where j refers to any particular but unspecified response. The estimated information in the joint occurrence of a stimulus and response is expressed as:

$$H(x,y) = \sum p_{ij} \log 1/p_{ij}$$

If stimuli and responses are completely independent, the information in their joint occurrence, $H(x,y)$, equals the sum of the individual information values-- $H(x) + H(y)$. However, if $H(x,y)$ is less than the sum of the individual information values then $H(x)$ and $H(y)$ overlap or share information. This shared information is expressed as:

$$T(x;y) = H(x) + H(y) - H(x,y)$$

If one and only one response is associated with each stimulus then perfect transmission results with no loss of information or the addition of spurious information; $H(x) = H(y)$

$= H(x,y) = T(x;y)$. However, when different stimuli elicit the same response, input information is lost and the response is equivocal. Equivocation is expressed as:

$$H_y(x) = H(x) - T(x;y)$$

Likewise, when a single stimulus elicits different responses then information is added and ambiguity results. Ambiguity is expressed as:

$$H_x(y) = H(y) - T(x;y)$$

The application of information theory to absolute judgment of symbol magnitude shows we can generally distinguish among six alternatives of area changes and seven to eight alternatives of line length (Van Cott & Kinkade, 1972). If the stimulus set is increased beyond these optimum numbers, confusion increases and measures of information transmission become asymptotic. This point of maximum information transmission is called the channel capacity and varies depending on the particular stimulus dimension. For example, information transmitted by varying the position of a dot in space is optimized at ten alternatives while varying the intensity of an electrical shock to the skin is optimized at only three alternatives (Van Cott & Kinkade, 1972).

Miller (1956) proposes that we can generally distinguish between five and nine alternatives of a unidimensional continua. While recognizing differences in the information capacity among different continua, Miller also noted the narrow range of the values obtained from many absolute judgment experiments; mean information transmission of 2.6 bits, standard deviation of .6 bits and a one standard deviation range of four to ten

alternatives. On this basis he argued "...that we possess a finite and rather small capacity for making unidimensional judgments and that this capacity does not vary a great deal from one sensory attribute to another" (Miller, 1956, p. 86).

This rather consistent limitation on our ability to process information has been the focus of much research since Miller's (1956) paper proposing the magical number seven plus or minus two. Siegel (1972) attributes the limits in absolute judgment performance to extremely rapid forgetting. By controlling for retention interval and number of intervening items through data analysis, Siegel found that time alone (0-6 seconds) produced substantial forgetting and that the occurrence of even one intervening trial is highly interfering. Together these variables quickly reduced performance to an asymptotic level. Moray (1967) proposes a limited capacity central processor model in which performance is dependent upon cognitive demand. Greater processing resources are available if cognitive demand is reduced through practice or improved stimulus-response compatibility.

Other researchers have focused primarily on perceptual variables to explain the limits in absolute judgment. Garner (1953) shows a slight increase in information transmission by spacing stimuli equally on a scale of perceived discriminability rather than the more common methods based upon physical intensity. Increasing the stimulus range also produces a small but reliable increase in information transmission (Eriksen & Hake, 1955). Providing feedback is another technique to improve information transmission slightly (Alluisi, 1957). However, even

by optimizing stimulus range, discriminability and knowledge of results, the channel capacity is increased only slightly rather than eliminated entirely. In light of the sensory-perceptual and cognitive limitations to absolute judgment, an alternative and possibly more effective method to encode symbol magnitude information might be through the psychophysical scaling technique of absolute magnitude estimation.

S. S. Stevens (1975) was the first to suggest that in the more traditional scaling techniques of magnitude estimation and magnitude production individuals tend to pair numbers with sensations on an absolute rather than a ratio scale. That is, when no modulus or standard is designated, different groups of subjects are in close agreement on the values assigned the first stimulus under instructions to assign it whatever number seems appropriate.

The suggestion of an absolute coupling between numbers and psychological magnitudes led Hellman and Zwislocki (1961) to propose the concept of absolute magnitude estimation. In validating their modification of the magnitude estimation paradigm they found that scales produced under absolute magnitude estimation coincide closely among different groups of subjects; are not influenced by the magnitude of the first stimulus presented; do not depend upon experience with psychophysical scaling; and are not influenced by the location or extent of the stimulus range (Zwislocki & Goodman, 1980). These are all factors which may seriously influence the data collected under traditional ratio scaling paradigms (Poulton, 1968).

These features make absolute magnitude estimation especially attractive for scaling symbol magnitude across the wide range of individuals and conditions encountered in an operational environment. Using absolute magnitude estimation, operators assign a number to each symbol in a visual code in such a way that their impression of how large the number is matches their impression of the symbol's magnitude. Thus changes in perceived symbol magnitude would convey information about changes in the displayed parameter. Symbol magnitude changes interpreted in this way could represent information currently suitable for check reading. This type of coding would be particularly appropriate for computer controlled CRT displays in which dynamic variations are easily manipulated and displayed. Figure 1 presents illustrations of this concept as it might be applied to visual displays.

INSERT FIGURE 1 ABOUT HERE

Although there has been no direct comparison of information transmission under absolute judgment and absolute magnitude estimation, there has been some effort to present a cognitive theory of psychophysics that unifies results from the many psychophysical methods. Baird (1970a, 1970b) argues that the coding strategy used to manipulate information depends upon the particular experimental procedure used. Different psychophysical

scales result from different methods because each requires a unique coding system limited by specific perceptual and memory constraints. Thus the sensitivity of a subject varies as a function of the methods used. Although there is no data comparing perceptual sensitivity or cognitive capacity under absolute judgment and absolute magnitude estimation, Baird holds that channel capacity is directly related to perceptual sensitivity; the greater the channel capacity the greater the sensitivity. Baird, Romer and Stein (1970) validated this concept by obtaining both power function exponents for magnitude estimation of line length and complex figure area and information measures of the same stimuli using absolute judgment. Their results support Baird's position in that the ordinal relation of exponents (length higher than area) was the same as the ordinal relation of information measures.

The objective of this study is to determine the usefulness and accuracy of information transmission under absolute magnitude estimation scaling versus absolute judgment scaling. Because absolute magnitude estimation scaling requires only that subjects match numerical magnitude to symbol magnitude I would hypothesize reduced cognitive demand compared to the memorization and retrieval required under absolute judgment scaling. The reduced demand on information processing resources should result in increased symbol identification performance (Miller, 1956; Morey, 1967; Siegel, 1970). Information capacity using the absolute coupling between numbers and psychological magnitudes as suggested by Zwislocki and Goodman (1980) can be shown by

information analysis which essentially describes the overlap and variability of responses to specific stimuli. Information transmission is increased to the degree that each stimulus evokes a unique response or responses. If in absolute magnitude estimation the stimulus-response pairing is more effective than that in absolute judgment, then information transmission should also be greater.

METHOD

Subjects. Twenty-four Tufts University undergraduate students participated in the study in partial fulfillment of course requirements. None had previous experience with ratio scaling or formal testing of absolute judgment skills. Participants were not tested for normal vision.

Design. The hypothesis was tested using a split-plot factorial design with one between subjects factor and two within subjects factors. Series of lines and ellipses each with 4, 8 and 12 intermediate sizes were presented to 12 subjects under the absolute judgment (AJ) paradigm and to an additional 12 subjects under the absolute magnitude estimation (AME) paradigm. The dependent variable is the subject's absolute magnitude estimate or absolute identification of the stimulus for the AME or AJ condition respectively. The independent variables are the scaling method (AJ or AME), figure (line or ellipse) and series (4, 8 and 12 stimulus magnitudes). Presentation of lines or ellipses was random and series order was counterbalanced.

Procedure. Figures were generated and displayed by an Apple Macintosh computer (22 cm diagonal display) using experimenter developed BASIC programs. Subjects made 15 responses without feedback to each stimulus presented in random order. Under AJ, they identified stimuli according to values previously assigned during practice trials in which they scaled each symbol presented randomly five times with feedback. Under AME, subjects scaled symbol magnitude under instructions to assign numbers to each stimulus so their impression of how large the number is matches their impression of figure magnitude. Subjects were introduced to the applicable scaling paradigm using the instructions in Appendix A. Practice trials were not required under AME. For both scaling paradigms, symbols were shown for 1.5 seconds after which the display was cleared and the response entered via keyboard. Each subject provided 720 responses which were stored as stimulus-response pairs in data files on micro floppy disks. Total time including instructions and breaks was about 1.5 hours for subjects in the AJ condition and about 1.0 hours for subjects in the AME condition.

Materials. The stimuli are lines and outline ellipses each in series of 4, 8 and 12 intermediate sizes. Stimulus sizes vary symmetrically about the center of the display and are presented randomly within each series. To maximize discrimination between stimuli given the limited working area of the display (17.5 cm X 11.5 cm) stimuli are scaled using the generalized form of Weber's law-- Difference Level = k(stimulus) + c -- where k and c are constants. This function is preferred over the original form of

Weber's law because it accounts for the difficulty of discriminating minor changes in the progression of small stimuli (Ono, 1967). In the AJ condition, stimuli are assigned the numbers 1-4, 1-8 or 1-12 as required with the smallest stimulus given the smallest number and the largest stimulus assigned the largest number. Stimulus dimensions for lines and ellipses are presented in Tables 1 and 2 respectively.

INSERT TABLE 1 ABOUT HERE

INSERT TABLE 2 ABOUT HERE

RESULTS

Information Measures. Information measures were computed by experimenter developed BASIC programs according to information theory procedures described by Attneave (1959) and Sheridan and Ferrell (1974). Measures of information transmission, equivocation, ambiguity and response alternatives were subjected to analysis of variance. Response alternatives represents the number of unique numerical responses used to describe symbol magnitude under AME scaling. Effects of Scaling Paradigm, Figure and Series were all significant in terms of information transmission, equivocation and ambiguity measures ($p<.01$).

Additionally, the Scaling X Series interaction under ambiguity measures was also significant ($p<.01$). All significant effects are summarized in Table 3. Ambiguity measures required transformation to meet underlying assumptions regarding homogeneity of variance. In addition, two interactions considered significant by the analysis of variance (Scaling X Series for both information transmission and equivocation) did not reach significance by an adjusted F test which accounts for symmetry of the variance/covariance matrix (Kirk, 1982). Full analysis of variance summary tables are provided in Appendix B.

INSERT TABLE 3 ABOUT HERE

Figure 2 collapses the data across Figures to show the progression of the information measures. As input information increases, information transmission also increases but at a much slower rate. Measures of equivocation and ambiguity also increase as more errors are made due to confusion among the additional stimuli of the larger series.

INSERT FIGURE 2 ABOUT HERE

Although significant, the magnitude of the difference in information measures between scaling paradigms is small. As the series progress from smallest to largest, the mean difference in information transmission, equivocation and ambiguity is .24, .24 and 1.37 bits respectively. Additionally, the ratio of treatment variance to total variance for Scaling Paradigm is larger than that of Figure but smaller than that of Series for information transmission and for equivocation (see Figure 3). This rank ordering indicates the influence of Scaling Paradigm compared to the better understood affects of Figure and Series.

INSERT FIGURE 3 ABOUT HERE

Figure 4 shows that judgments of lines were performed with more information transmission, less equivocation and less ambiguity than were judgments of ellipses. It is interesting to note that judgments of lines under AME were only as efficient as judgments of ellipses under AJ in terms of information transmission and equivocation. Thus scaling performance of simple stimuli using AME is reduced to a level comparable to scaling complex stimuli under AJ.

INSERT FIGURE 4 ABOUT HERE

Psychophysical Functions. Psychophysical power functions for AME scaling of lines and ellipses in the largest series were computed using median response values according to procedures described by Gescheider (1985). The exponent of the power function is .998 for lines and .654 for ellipses. Figure 5 shows the plot in logarithmic coordinates of median magnitude estimate versus stimulus intensity for line length and ellipse area. While the exponent for length is typical of that found in the literature, that of area is slightly smaller than the .7 to .8 usually obtained from the various psychophysical methods (Gescheider, 1985; Baird & Noma, 1978; Zwislocki & Goodman, 1980; Teghtsoonian, 1965). Figure 6 presents the range of median magnitude estimates for each stimulus in the twelve line series. The logarithmic plot emphasizes the extreme range and wide variability of responses which was also present in the scaling of ellipse area.

INSERT FIGURE 5 ABOUT HERE

INSERT FIGURE 6 ABOUT HERE

DISCUSSION

Information Transmitted. Few mistakes are made with the smallest series but the information transmission values begin to asymptote with the larger series. The channel capacities obtained from this experiment are 2.66 bits for AJ scaling and 2.34 bits for AME scaling (see Figure 7). This represents an increase of one extra stimulus alternative under AJ scaling. More information is transmitted under AJ than under AME, however, the fidelity of the system (ratio of information input to information transmitted) under either scaling method is maximized at four equally likely alternatives. When the codes in this experiment were increased to eight and twelve equally likely alternatives discrimination remained limited to about five values and so there was little advantage gained from the additional stimuli.

However, it is not strictly the number of alternatives which determines information content but rather their probability of occurrence (Sheridan & Ferrell, 1974). Thus one code may consist of three equally likely alternatives and another may consist of ten alternatives with varying probabilities of occurrence but yet both may have equal stimulus information values. Because the stimuli in this experiment are equally likely, the information contained in each series is maximized at log base two of the number of alternatives-- 2, 3, and 3.58 bits for the 4, 8 and 12 stimuli series respectively. Interpreting the channel capacity in terms of equally likely alternatives is simply a convenient way to express the performance of the communication system.

INSERT FIGURE 7 ABOUT HERE

The assumption that cognitive demand under AME is less than that under AJ is not supported by the data. Based upon Moray's (1967) limited central processor model, it is the functions performed on the input information which take up the capacity of the transmission system and, although the overall capacity of the processor is limited, the brain can divide up this capacity and allocate it in different ways depending on the task. The greater demand for information processing resources required by AME scaling reduces the capacity of the transmission channel, leaving less to be used as a transmission line and consequently reducing information transmission performance. The increased cognitive demand in AME may result from the need to first interpret stimulus magnitude and next to transform psychological magnitude to numerical magnitude.

The results are consistent with those of Baird, Romer and Stein (1970) in that the ordinal relation of the channel capacity for lines and ellipses (2.8 and 2.5 bits for AJ; 2.5 and 2.2 bits for AME) is the same as that for the power function exponents of line length and ellipse area (.998 and .654 respectively). Baird's (1970a, 1970b) position that it is the information coding strategy that defines the cognitive constraints seems to hold although not in the direction expected.

<u>Ambiguity</u>. The analysis of variance indicates a significant Scaling Paradigm X Series interaction for ambiguity measures ($F(2,44)=8.42$, $p=.0008$). When the same stimulus leads to many different responses as it does in AME, there is variability in the output which does not correspond to variability in the input. Ambiguity is a composite measure of this variability (Sheridan & Ferrell, 1974). While ambiguity under AJ increases steadily with an increase in the number of stimuli, there is a sharp change between the last two series under AME scaling (see Figure 8). This change is due to a sharp increase in the average number of response alternatives used to describe symbol magnitude in the largest series. Every unique number assigned any stimulus in a series is considered a unique response alternative. For example, one subject used the following twelve numbers to describe the magnitude of four stimulus lines:

2 4 5 7 8 9 10 11 12 17 18 19

INSERT FIGURE 8 ABOUT HERE

Although each number is used more than once, in total they represent all the alternatives which were paired to specific stimuli. The average number of unique responses used to describe symbols in the 4 stimuli series is 18 and for the 8 and 12 stimuli series is 25 and 41 respectively. Consistent with information theory, Figure 9 shows that an increase in response

variability leads to an increase in ambiguity. Thus the more than twofold increase in the difference in response alternatives between the first two and last two series leads to a correspondingly large increase in ambiguity measures. Perhaps the change is a function of both the number of stimuli and the confusion among stimuli. As stimuli are added, more responses are used to describe them. However, confusion also becomes greater and causes a further increase in the number of response alternatives. On the other hand, the number of response alternatives is not affected by the type of figure presented ($F(1,11)=.1285$, $p=.7268$). It seems the number of unique responses is dependent on the number of stimuli but independent of stimulus complexity. It is also interesting to note by the asymptotic nature of the curve in Figure 9 that beyond 60 unique responses ambiguity remains level at about 3 bits. Apparently the consistency of stimulus-response pairings remains level even with the additional responses.

INSERT FIGURE 9 ABOUT HERE

The additional response alternatives given under AME scaling does not necessarily dictate a degradation in information transmission. Figure 10 is the stimulus response matrix for a subject scaling four line lengths under AME. Forty response alternatives describe the magnitude of only four stimuli.

Ambiguity in this example is 3.08 bits while information transmission is perfect (2.0 bits). The tendency for a single stimulus to give rise to different responses will not reduce information transmission if the pairing is consistent as in this example. Figure 10 also shows that information theory is independent of the nominal correctness of responses; it measures only consistency of association (Sheridan & Ferrell, 1974). Although the second stimulus in the series received three median magnitude estimates (i.e., 30, 31, 50) that are appropriate for the next larger stimulus, the association is consistent and so information transmission is perfect.

INSERT FIGURE 10 ABOUT HERE

Ambiguity under AJ scaling tends to be much lower than that under AME because there are as many allowable responses as there are stimuli (Eriksen and Hake, 1955). Mean ambiguity for AJ and AME is .507 and 1.879 bits respectively. Additionally, under AJ scaling both ambiguity and equivocation are closely related (see Figure 2). The correlation coefficient for equivocation versus ambiguity is .997 and the regression equation is:

$$\text{equivocation (bits)} = 0.0 + 1.07 \text{ ambiguity (bits)}$$

Thus we can predict that the loss of input information and the addition of spurious information are equal as additional stimuli are added in an AJ task.

Equivocation. Equivocation is another useful indicator of symbol identification performance. When different stimulus inputs elicit the same response, the subject does not discriminate between stimuli and hence there is a loss of input information (Sheridan and Ferrell, 1974). Mean equivocation for AJ and AME scaling is .543 and .780 bits respectively. Why less information is lost under AJ than under AME for the same stimuli is not clear. Perhaps it is because subjects under AJ are instructed to match assigned responses to stimuli that there is improved stimulus-response pairings and hence improved apparent discrimination. Subjects under AME scaling, on the other hand, were required only to assign a numerical magnitude to each stimulus, independent of its relation to other stimuli.

Component Relationships. Figure 11 depicts the relationship between the various information components. The mean information values are expressed as a percentage of the largest information component, the estimated information in the joint occurrence of a stimulus and response for AME scaling or H(x,y). The percentage conversion is used because mean measures rather than individual measures are represented. For an individual, H(x,y) equals the sum of equivocation, ambiguity and information transmission as shown by the relationship of these measures in Figure 11. However, mean values are used to represent group behavior and thus the sum of the components will not necessarily equal the mean H(x,y) component. Expressing the components as ratios maintains the relative magnitude of the measures while presenting them in a form convenient for comparison across scaling methods.

Because stimulus information, information transmission and equivocation are similar under both scaling paradigms while ambiguity and information output is greater under AME scaling, the 'endpoints' of the AME representation must expand to account for the greater amount of information in the channel. This expansion is represented by the $H(x,y)$ value which is consequently larger under AME scaling. It is also interesting to note that response information or $H(y)$ represents the total information in the output of the channel and is independent of the information actually shared or that which is lost or added to the system. It is even greater than the information input under AME scaling due to the excess noise in the channel.

INSERT FIGURE 11 ABOUT HERE

Learning and Practice. Learning and practice generally improves the ability to judge unidimensional stimuli. Presumably, the stimulus-response mapping becomes more efficient and refined over time (Moray, 1967). With visual stimuli, perceptual learning should lead to a better assessment of relevant stimulus dimensions. Only necessary dimensions are then analyzed to identify the required signal while irrelevant or redundant ones are ignored thus freeing extra processing capacity. Additionally, practice should also lead to more efficient coding methods to transform the input into a more manageable form (e.g., chunking).

A successful transformation would free further processing resources. To better understand the effects of practice and learning in psychophysical scaling, Information transmission measures were computed for the first half (1-8) and second half (9-15) of the responses to each stimulus under both scaling paradigms. Analysis of variance showed no significant differences in split-half information transmission measures under AJ or AME scaling ($F(1,22)=1.00$, $p=.37$). Split-half mean information transmission values are 2.50 and 2.49 bits for AJ scaling and 2.29 and 2.33 bits for AME scaling.

Perhaps the complexity of the mapping transformation under both scaling paradigms is already at a minimum, making it impossible to increase processing capacity through more efficient coding. This suggests that there is a very direct relationship between input and output in both scaling paradigms and that performance improvements will have to come from some other manipulation. Unfortunately, the remaining alternative of increasing information transmission through practice is not supported by the data. However, the lack of significance may be due to the absence of feedback and because there were too few trials for prolonged practice.

<u>Psychophysical Power Functions</u>. The potential for practical application of AME as envisioned by Zwislocki and Goodman (1980) is not well supported by the data. The authors propose that because absolute scales are not influenced by the range of magnitudes involved and because they show little invariance among experimental groups, they should have widespread validity and

could be used, for example, to scale loudness of noise at some location in New York City which would be roughly comparable with the loudness of the same noise if it were scaled at some location in Los Angeles by a different group of people. Although the variability in median magnitude estimations obtained in this study (see Figure 6) would not preclude such a general application on a limited scale, it does eliminate more refined applications such as the information encoding scheme proposed here.

The ogive like form of the power functions plotted in Figure 5 was also shown by Zwislocki and Goodman (1980) in testing inexperienced subjects though no explanation is given for the phenomena. However, their results indicate that inexperienced subjects tend to assign numbers that appear too large to the largest stimuli and numbers that appear too small to the smallest stimuli. As subjects gain experience with the scaling paradigm and stimuli during subsequent trials, the power function plots not only loose their ogive like form but also drop in absolute position. The authors attribute this drop to a decrease in the magnitudes of the numbers assigned to stimuli.

This range effect is opposite that normally encountered in psychophysical experiments. Stevens (1975) frequently observed that subjects were reluctant to make extremely high or extremely low judgments even though they may be correct in terms of their perceptions. He identified three factors as possible contributors to this effect. First, the observer favors the more comfortable stimulus level. When required to judge stimuli at a

very high level, judgments tend to fall more toward the lower levels. Conversely, when observers must strain to perceive weak stimuli, judgments are usually higher than they should be. Second, observers differ in the degree in which they seem willing to explore wide ranges of the variable. Overly cautious or constrained observers show the strongest regression effects. Third, the observer's judgment of a particular stimulus seems to depend to some extent upon the stimulus that preceded it. A stimulus tends to be judged lower when preceded by a lower stimulus than when preceded by a higher stimulus.

However, the results of this study are opposite to those expected from Stevens' factors. Rather than being conservative in their expressions of stimulus magnitude, subjects assigned numbers that appear too large to the larger stimuli and numbers that appear too small to the smaller stimuli. It might be that the smallest and largest stimuli acted as perceptual anchors because of their easily identifiable relationship to the display boundaries. The uppermost stimuli were perceived as 'very large' because those were the largest which could be presented while the smaller stimuli were perceived as 'very small' because those were the smallest which could be presented. These perceptions could skew the numerical responses toward overestimation and underestimation respectively. The hypothesis could be tested by presenting stimuli under a reduction condition of viewing--without reference to visual boundaries. In practice, however, complete reduction is difficult to achieve. Although the power function seems to lose its ogive form with practice, it's very

pervasive and easily recognizable in the AME research. It is certain to be encountered in future experiments and is an issue which should be resolved.

The power function exponent for ellipse area (.654) is slightly depressed for simple scaling of figure area and is closer to that obtained with more complex stimuli such as irregular figures or three dimensional stimuli (Teghtsoonian, 1965). The results might be due to the psychophysical scaling technique, to the relatively small size of stimuli tested or even to statistical variations and cannot be interpreted without further testing.

CONCLUSION

Overall, the data does not support the usefulness and accuracy of encoding information through AME scaling versus the more traditional AJ paradigm. Under AJ, information transmission is higher and equivocation and ambiguity measures are lower than those obtained under AME scaling. Although statistically significant, the magnitude of the differences does not preclude the use of AME for processing information encoded through symbol magnitude. Rather it is the wide variability in median magnitude estimations that makes it difficult to reach any common ground for symbol interpretation.

Rather than relying on absolute magnitude estimation for direct interpretation of symbol magnitude, an alternative might be to use stimulus intensity as a supporting element in

control/display design. For example, to 'psychologically support' the linear and figure display illustrated in Figure 12, one could design the scale marks or figure indicator to be compatible with the psychophysical power function. In this way, actual changes in displacement would be consistent with the psychological perception of the magnitude of those changes.

INSERT FIGURE 12 ABOUT HERE

Although the original hypothesis is not supported by the data, this study suggests that the absence of models describing cognitive behavior under the different psychophysical scaling methods is a prime area for further investigation. Current research on central mental processes should be able to answer questions which were once postponed for lack of understanding and scarcity of experimental techniques. The total sensory input capacity of the human system is about 10^9 bits/second (Woodson, 1981). Compared to this we see that subjects can identify with minimum error only three equally likely visual stimuli varying in length or area. Research must must be directed at separating the sequential phases of information processing (sensation, perception, decision, response, etc.,) and determining precisely where capacity is limited and how to manipulate the stimulus or the operator to maximize information processing.

REFERENCES

Alluisi, E. A. (1957). Conditions Affecting the Amount of Information in Absolute Judgments. Psychological Review, 64(2), 97-103.

Attneave, F. (1959). Applications of Information Theory to Psychology. New York: Holt, Rinehart and Winston, Inc.

Bainbridge, L. (1975). Measuring by Judgment. Applied Ergonomics, 6(1). 9-16.

Baird, J. C. (1970a). A Cognitive Theory of Psychophysics I. Scandinavian Journal of Psychology, 2, 35-46.

Baird, J. C. (1970b). A Cognitive Theory of Psychophysics II. Scandinavian Journal of Psychology, 2, 89-102.

Baird, J. C., Romer, D. & Stein, T. (1970). Test of a Cognitive Theory of Psychophysics: Size Discrimination. Perceptual and Motor Skills, 30, 495-501.

Baird, J. C. & Noma, E. (1978). Fundamentals of Scaling and Psychophysics. New York: John Wiley & Sons.

Baker, C. A. & Grether, W. F. (1954). Visual Presentation of Information. WADC TR 54-160. Wright Air Development Center, Wright Patterson Air Force Base, Ohio.

Eriksen, C. W. & Hake, H. W. (1955). Absolute Judgments as a Function of Stimulus Range and Number of Stimulus and Response Categories. Journal of Experimental Psychology, 49(5), 323-332.

Garner, W. R. (1953). An Information Analysis of Absolute Judgments of Loudness. Journal of Experimental Psychology, 46(5), 373-380.

Garner, W. R. & Hake, H. W. (1951). The Amount of Information in Absolute Judgments. Psychological Review, 58, 446-459.

Gescheider, G. A. (1985). Psychophysics: Method, Theory and Application. New Jersey: Lawrence Erlbaum Associates.

Hellman, R. P. & Zwislocki, J. (1961). Some Factors Affecting Estimation of Loudness. Journal of the Acoustical Society of America, 33, 687-694.

Kirk, R. E. (1982). Experimental Design, 2nd ed. Monterey, California: Brooks/Cole Publishing Company.

Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. Psychological Review, 63(2), 81-97.

Moray, N. (1967). Where is Capacity Limited? A Survey and a Model. Acta Psychologica, 27, 84-92.

Ono, H. (1967). Difference Threshold for Stimulus Length Under Simultaneous and Nonsimultaneous Viewing Conditions. Perception and Psychophysics, 2, 201-207.

Poulton, E. C. (1968). The New Psychophysics: Six Models for Magnitude Estimation. Psychological Bulletin, 69(1), 1-19.

Sheridan, T. B. & Ferrell, W. R. (1974). Man-Machine Systems: Information, Control, and Decision Models of Human Performance. Cambridge, Massachusetts: MIT Press.

Siegel, W. (1972). Memory Effects in the Method of Absolute Judgment. Journal of Experimental Psychology, 94(2), 121-131.

Stevens, S. S. (1975). Psychophysics. New York: John Wiley & Sons.

Teghtsoonian, M. (1965). The Judgment of Size. American Journal of Psychology, 78, 392-402.

Van Cott, H. P. & Kinkade, R. G. (Eds.) (1972). Human Engineering Guide to Equipment Design. Washington D. C. : U. S. Government Printing Office.

Woodson, W. E. (1981). Human Factors Design Handbook. New York: McGraw-Hill Book Company.

Zwislocki, J. & Goodman, D. A. (1980). Absolute Scaling of Sensory Magnitudes: A Validation. Perception and Psychophysics, 28(1), 28-38.

Table 1
Stimulus dimensions for lines which were presented horizontally and symmetrically about the center of the display.

STIMULUS	LENGTH (4)[1]	LENGTH (8)[2]	LENGTH (12)[3]
1	9(mm)	6(mm)	3(mm)
2	26	14	9
3	63	25	17
4	144	39	26
5		57	36
6		82	48
7		116	61
8		160	77
9			95
10			117
11			141
12			170

[1] Stimulus function: DL (difference level)= 1.2(S) + 6mm. Each stimulus is 120% plus a constant of 6mm larger than the prior stimulus (S). Intervals were calculated based upon an initial length of 9mm.

[2] DL= .33(S) + 6mm, intervals calculated from an initial length of 6mm.

[3] DL= .16(S) + 6mm, intervals calculated from an initial length of 3mm.

Table 2
Stimulus dimensions for ellipses which were presented symmetrically from the center of the display. Minor to major axis ratio is 1:1.5 with the major axis horizontal.

STIMULUS	AREA (4)[1]	AREA (8)[2]	AREA (12)[3]
1	300 (mm^2)	200 (mm^2)	125 (mm^2)
2	1050	448	290
3	3375	855	514
4	10582	1522	820
5		2616	1235
6		4410	1799
7		7352	2567
8		12177	3611
9			5031
10			6962
11			9588
12			13160

[1] DL= 2.1(S) + $120mm^2$, calculated from an initial area of $300mm^2$.

[2] DL= .64(S) + $120mm^2$, calculated from an initial area of $200mm^2$.

[3] DL= .36(S) + $120mm^2$, calculated from an initial area of $125mm^2$.

Table 3
Analysis of variance for significant effects ($p<.05$).

SOURCE	F value(df)	P value
Information Transmitted		
AJ vs AME	14.80(1,22)	.0009
Line vs Ellipse	23.02(1,22)	.0001
4 vs 8 vs 12	127.61(2,44)	.0000
Equivocation		
AJ vs AME	14.82	.0009
Line vs Ellipse	23.02	.0001
4 vs 8 vs 12	240.22	.0000
Ambiguity		
AJ vs AME	32.21	.0000
Line vs Ellipse	10.76	.0034
4 vs 8 vs 12	58.71	.0000
AJ-4/8/12 vs AME-4/8/12	8.42(2,44)	.0008
Response Alternatives (AME only)		
4 vs 8 vs 12	16.12(2,22)	.0000

Figure Caption

Figure 1. Illustrations of information displayed through changes in symbol magnitude.

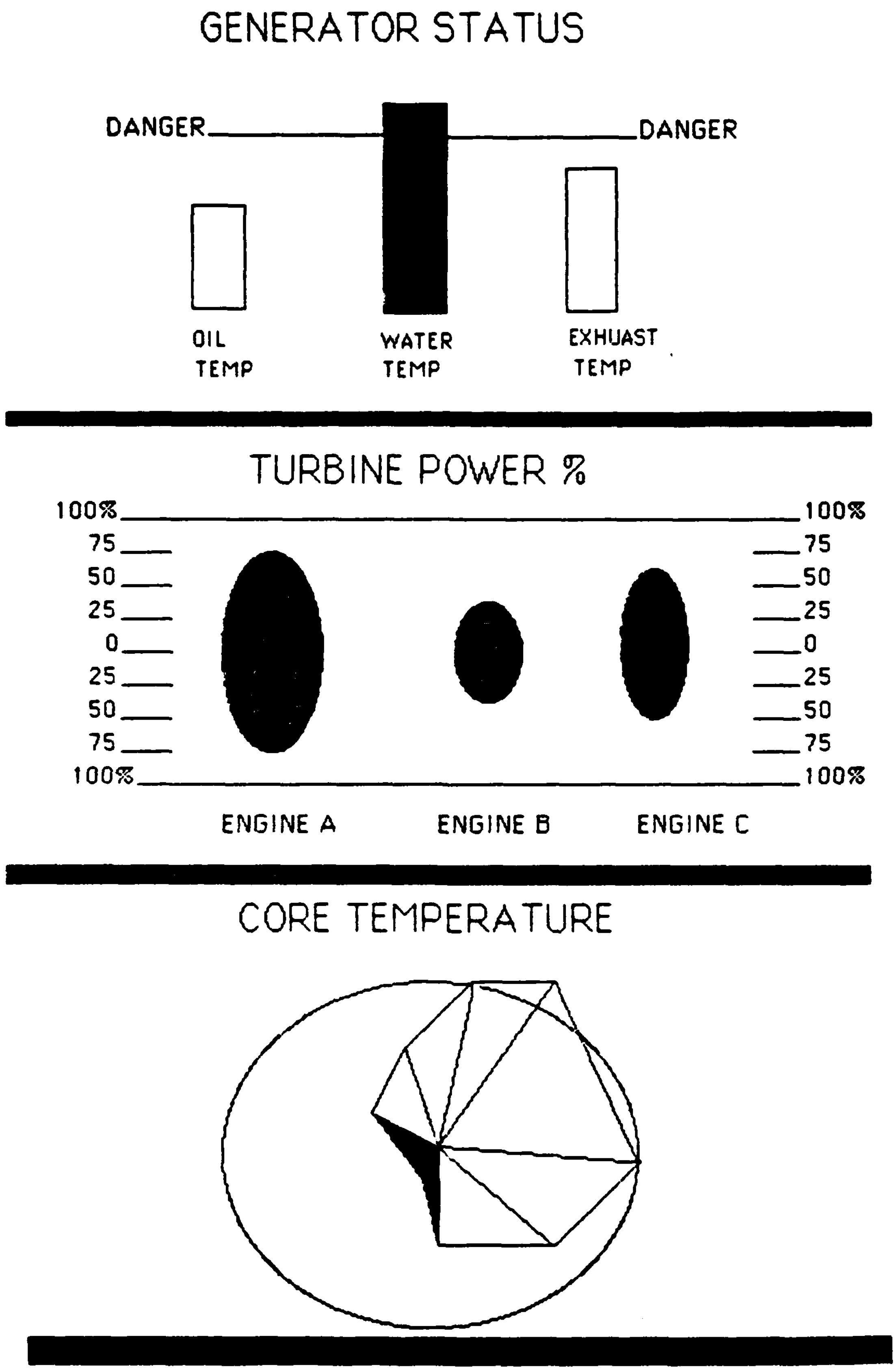
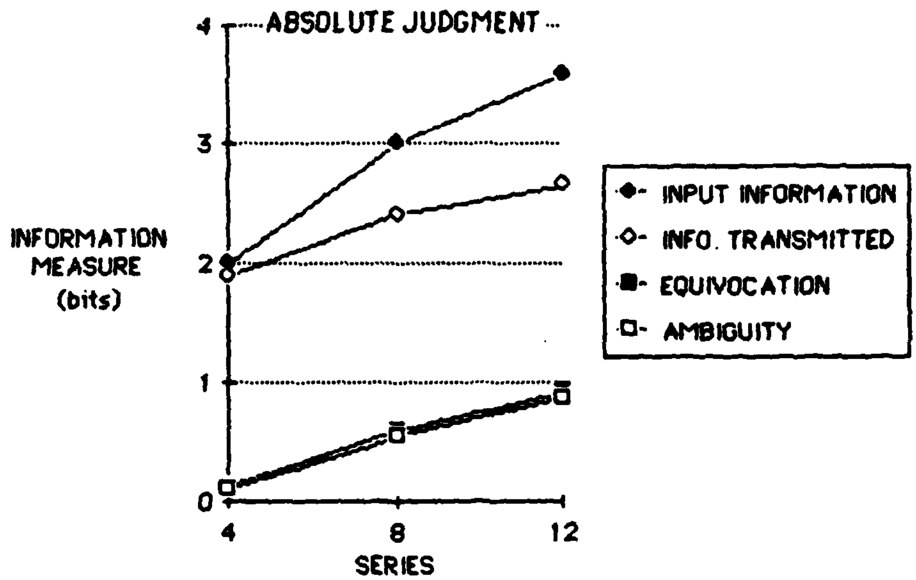

GENERATOR STATUS
DANGER
DANGER
OIL TEMP
WATER TEMP
EXHUAST TEMP
TURBINE POWER %
100%
75
50
25
0
25
50
75
100%
ENGINE A
ENGINE B
ENGINE C
CORE TEMPERATURE

Figure Caption

Figure 2. Information measures as a function of figure series (4, 8 or 12 intermediate sizes). Absolute judgment results shown above and absolute magnitude estimation results shown below.


ABSOLUTE JUDGMENT
INFORMATION MEASURE (bits)
0
1
2
3
4
4
8
12
SERIES
INPUT INFORMATION
INFO. TRANSMITTED
EQUIVOCATION
AMBIGUITY

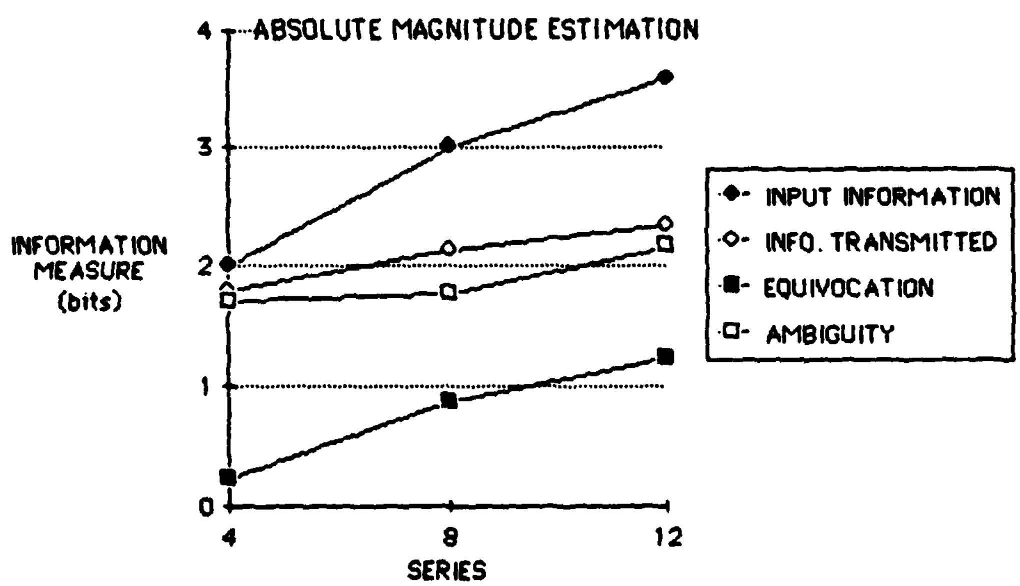

ABSOLUTE MAGNITUDE ESTIMATION
INFORMATION MEASURE (bits)
0
1
2
3
4
4
8
12
SERIES
INPUT INFORMATION
INFO. TRANSMITTED
EQUIVOCATION
AMBIGUITY

Figure Caption

Figure 3. Proportion of treatment variance to total variance for significant effects ($p<.05$).

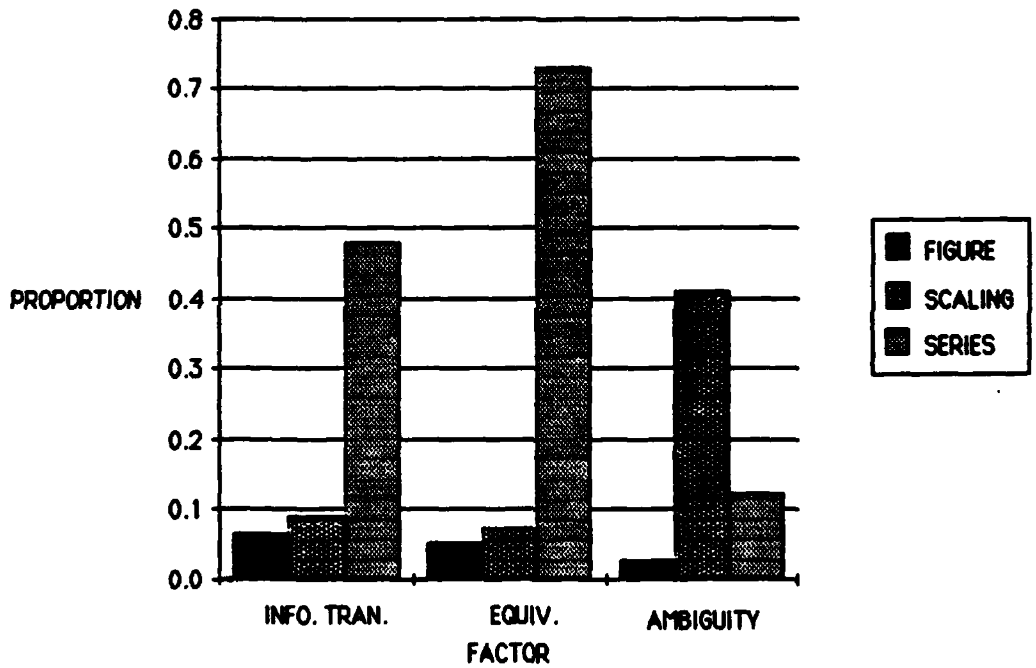
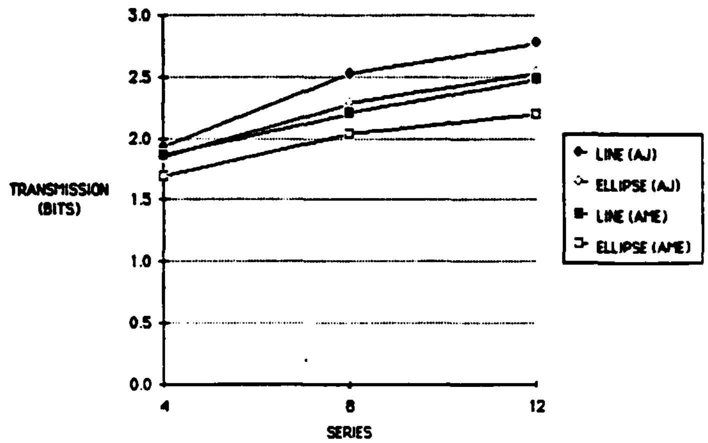
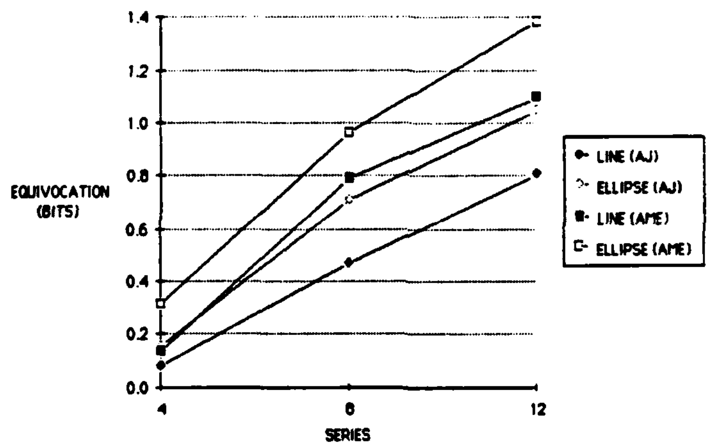

0.8
0.7
0.6
0.5
PROPORTION
0.4
0.3
0.2
0.1
0.0
INFO. TRAN.
EQUIV.
AMBIGUITY
FACTOR
FIGURE
SCALING
SERIES

Figure Caption

Figure 4. Mean information transmission (first graph), equivocation (second) and ambiguity (third) measures under absolute judgment and absolute magnitude estimation scaling.


3.0
2.5
2.0
1.5
1.0
0.5
0.0
TRANSMISSION (BITS)
4
8
12
SERIES
LINE (AJ)
ELLIPSE (AJ)
LINE (AME)
ELLIPSE (AME)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
EQUIVOCATION (BITS)
4
8
12
SERIES
LINE (AJ)
ELLIPSE (AJ)
LINE (AME)
ELLIPSE (AME)

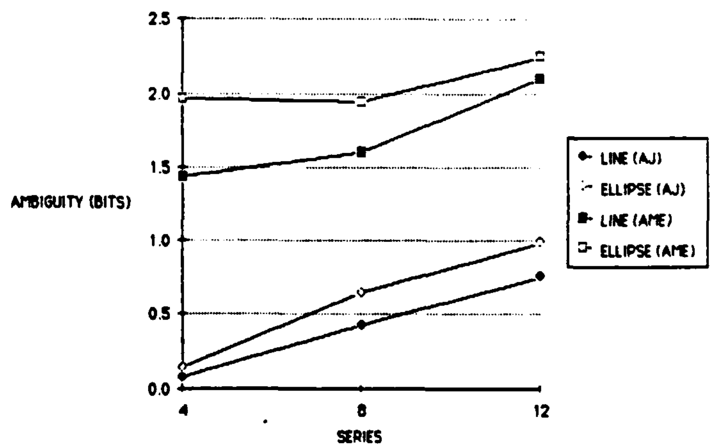
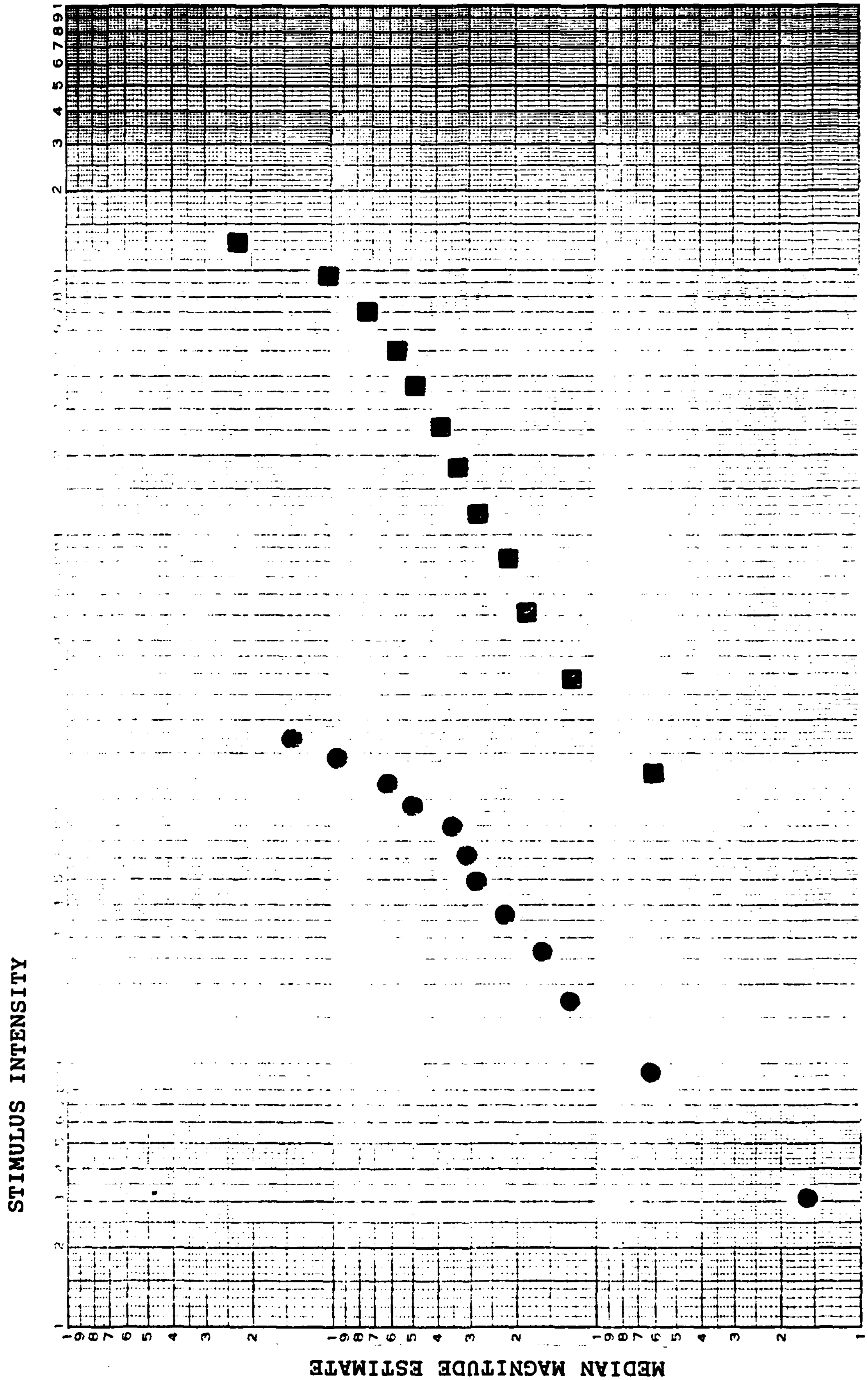

2.5
2.0
1.5
1.0
0.5
0.0
AMBIGUITY (BITS)
4
8
12
SERIES
LINE (AJ)
ELLIPSE (AJ)
LINE (AME)
ELLIPSE (AME)

Figure Caption

Figure 5. Median absolute magnitude estimate versus stimulus intensity for judgments of line length (circles) and ellipse area (squares) plotted on logarithmic axis. The slope of the line is .998 and .654 for length and area respectively.



11 Logarithmic, 3 × 5

Figure Caption

<u>Figure</u> <u>6</u>. Logarithmic plot of median magnitude estimations for the series of twelve line lengths. Each vertical line represents the range of the median magnitude estimates for the smallest stimuli (left) to the largest (right). Each slash represents one or more median magnitude estimates expressed within the given range.

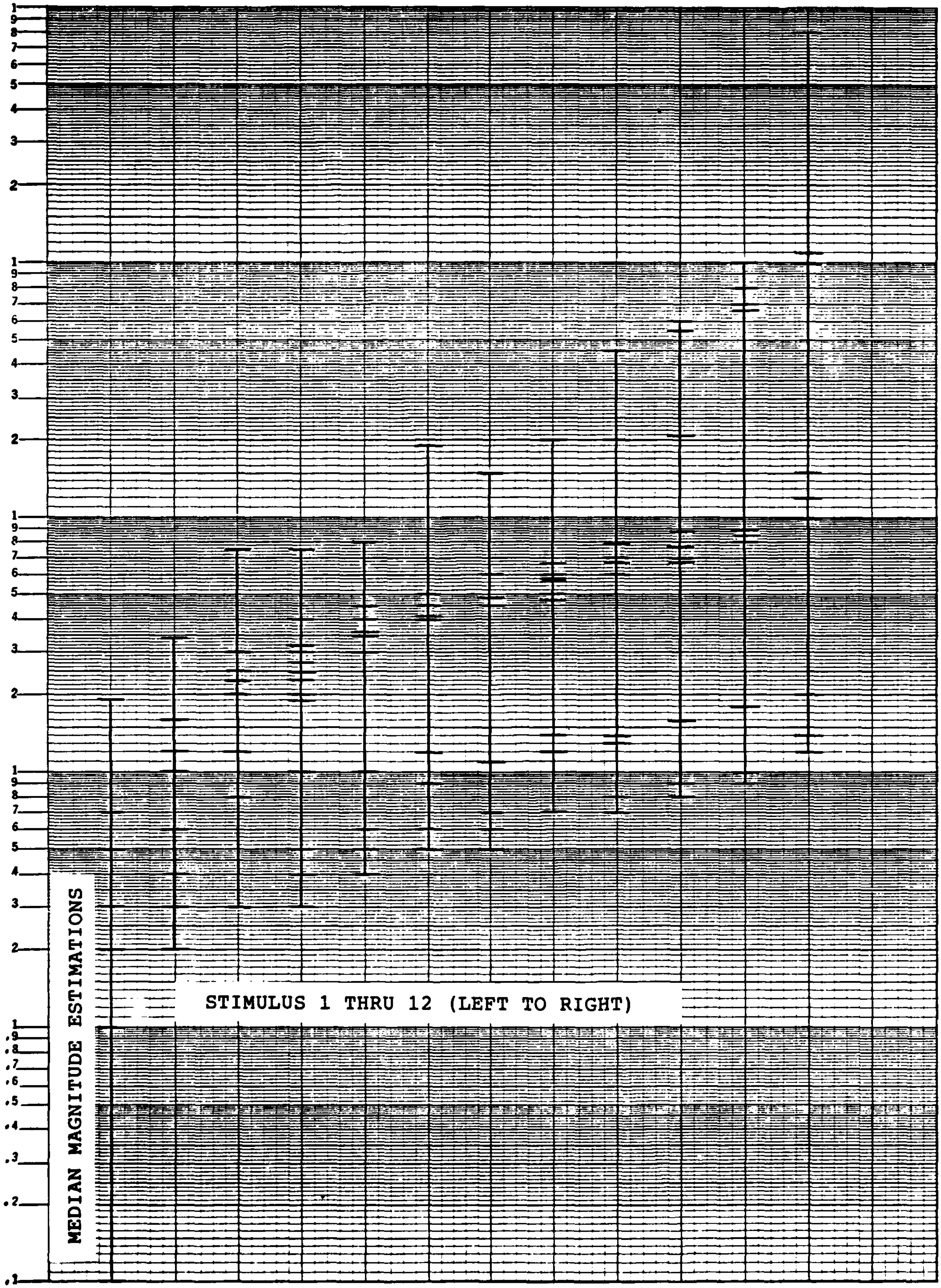

MEDIAN MAGNITUDE ESTIMATIONS
STIMULUS 1 THRU 12 (LEFT TO RIGHT)

Figure Caption

Figure 7. Information transmission versus stimulus information input for absolute judgment and absolute magnitude estimation scaling.

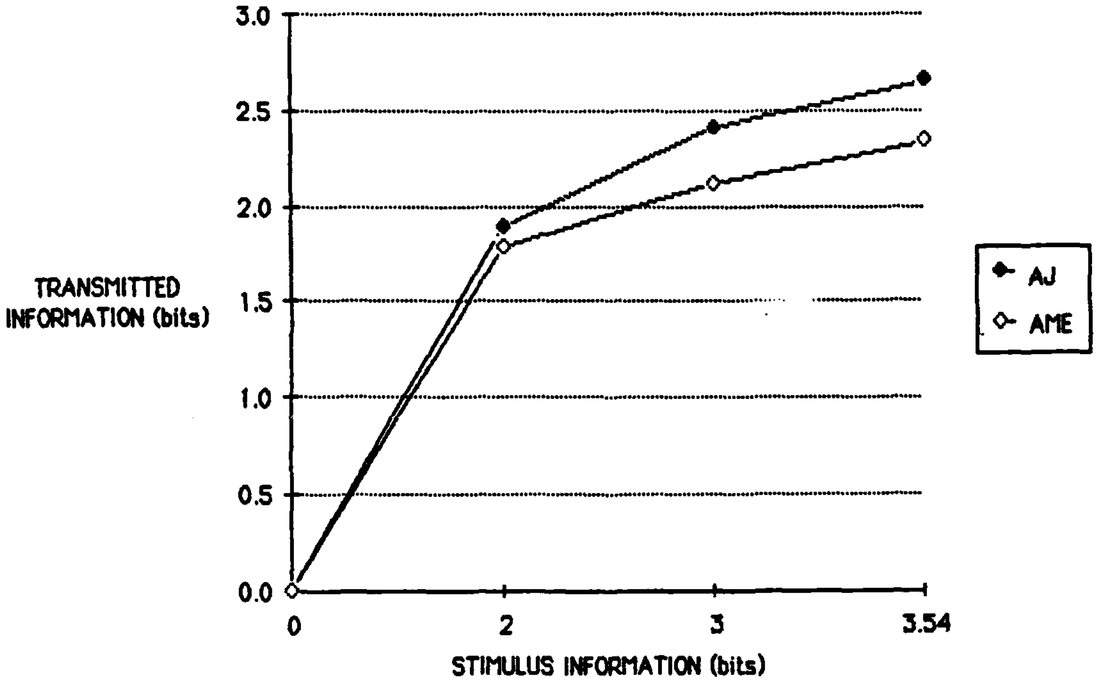

3.0
2.5
2.0
1.5
1.0
0.5
0.0
TRANSMITTED INFORMATION (bits)
0
2
3
3.54
STIMULUS INFORMATION (bits)
AJ
AME

Figure Caption

Figure 8. Ambiguity measures for absolute judgment and absolute magnitude estimation scaling.

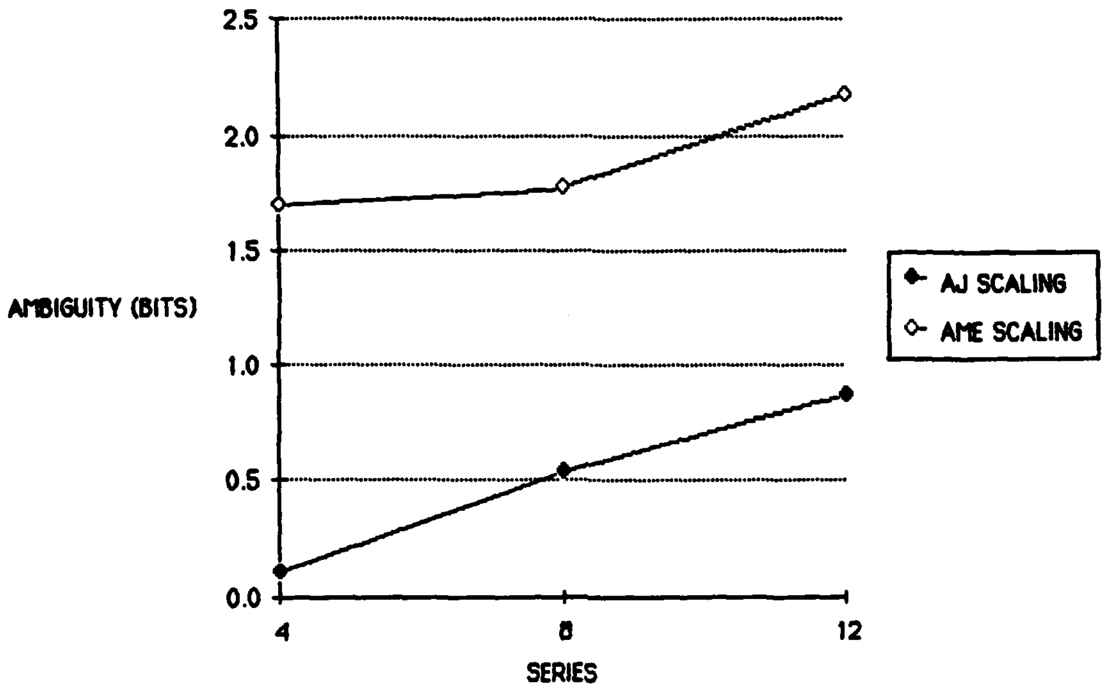

2.5
2.0
1.5
1.0
0.5
0.0
AMBIGUITY (BITS)
4
8
12
SERIES
AJ SCALING
AME SCALING

Figure Caption

Figure 9. Ambiguity versus the number of response alternatives to describe symbol magnitude.

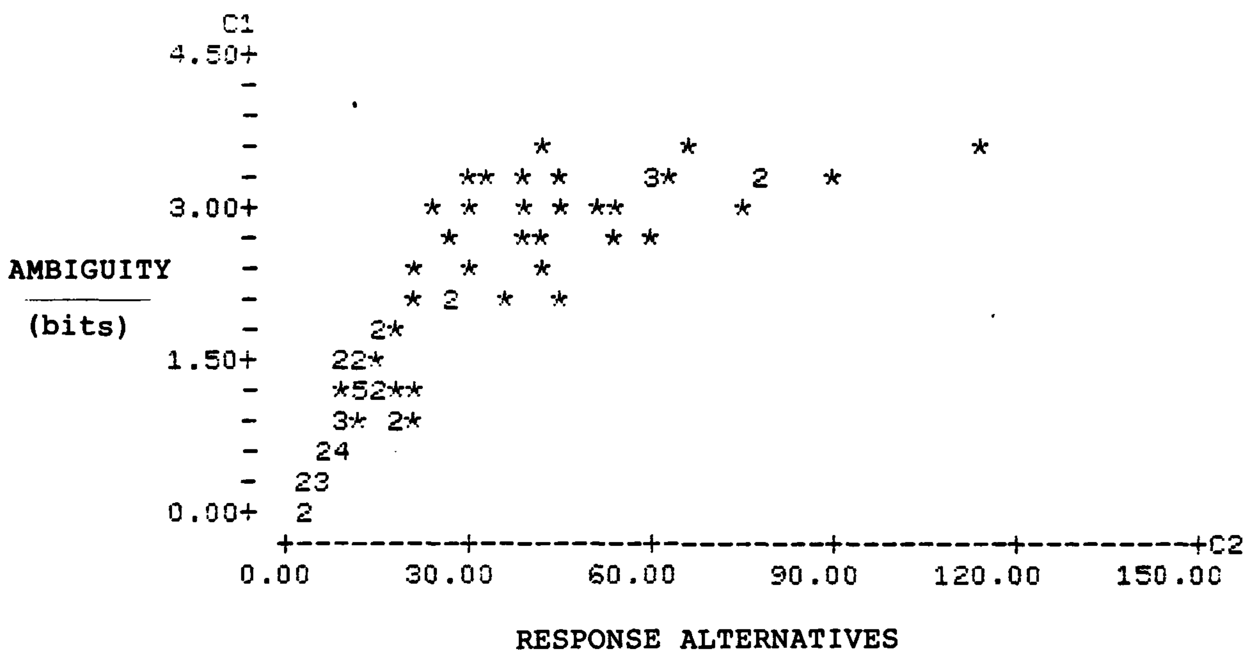

C1
4.50+
3.00+
1.50+
0.00+
AMBIGUITY
(bits)
C2
0.00
30.00
60.00
90.00
120.00
150.00
RESPONSE ALTERNATIVES

Figure Caption

Figure 10. Stimulus-response matrix for a subject judging four line lengths under absolute judgment. Numbers within the matrix represent frequency of associated responses. Information input = 2.0 bits, information transmission = 2.0 bits, equivocation = 0.0 bits and ambiguity = 3.08 bits.

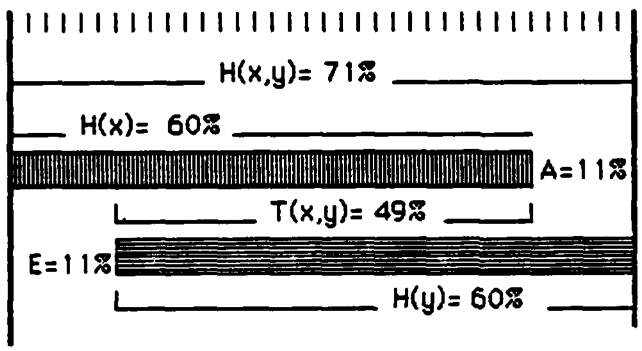
STIMULUS

RESPONSE

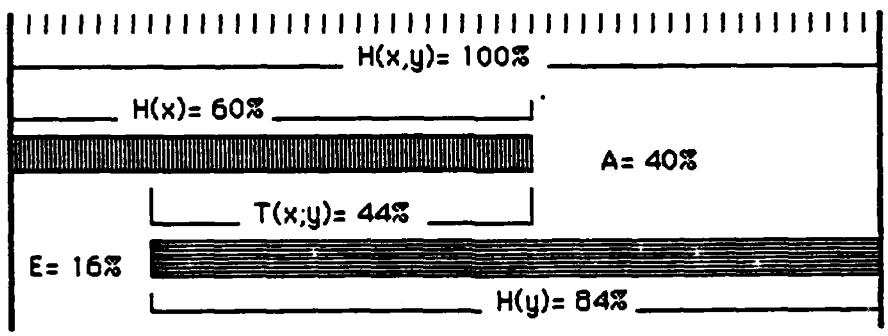
RESPONSE	1	2	3	4
1	2			
2	5			
3	4			
4	1			
5	3			
7		1		
8		1		
10		1		
11		1		
12		4		
13		1		
15		1		
21			1	
23			1	
30		3		
31		1		
40			1	
45			3	
50		1		
60			1	
65			2	
70			2	
75			1	
80			1	
100			1	
110			1	
190				1
200				1
225				1
250				1
290				1
300				1
310				1
390				1
400				1
670				2
700				1
800				1
900				1
1000				1

Figure Caption

Figure 11. Relationship between the various information components under absolute judgment and absolute magnitude estimation scaling. Measures are expressed as a percentage of H(x,y) in absolute magnitude estimation scaling (4.7 bits).



AJ SCALING



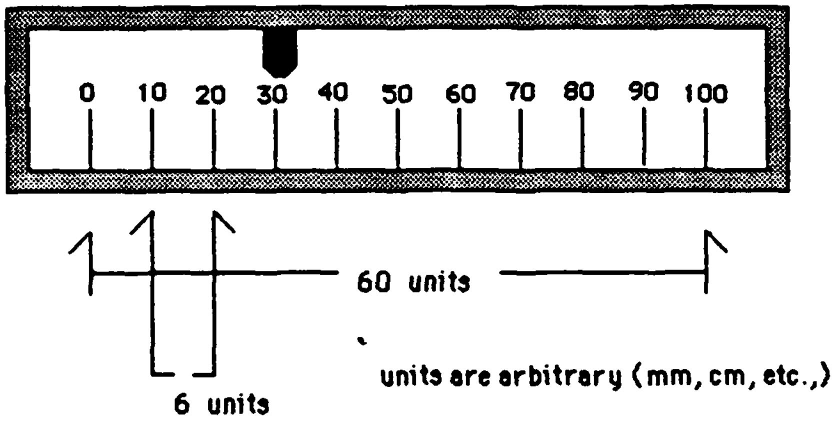
AME SCALING

Figure Caption

Figure 12. Examples of linear and area displays using the psychophysical power function as a design principle.

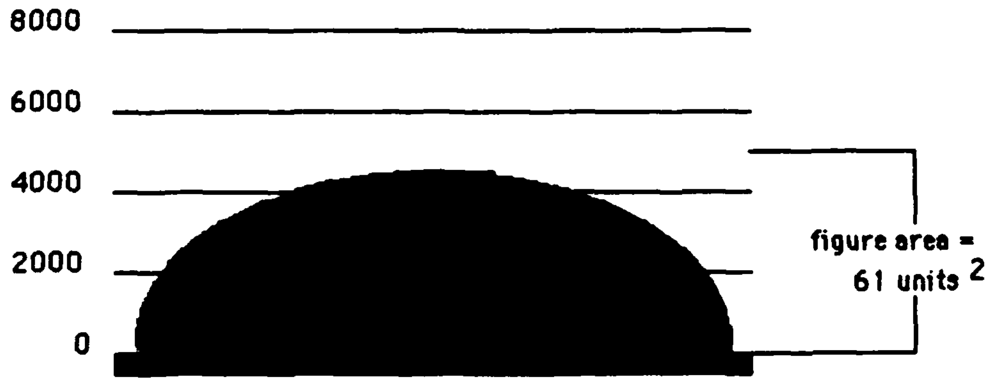
Linear display based upon design principle:

perceived value= $(\text{physical value})^{.998}$



Area display based upon design principle

perceived value = $(\text{physical value})^{.654}$



APPENDIX A

TASK DESCRIPTION

ABSOLUTE JUDGMENT*: Your task is to identify a series of figures presented on the computer screen using a simple technique called absolute judgment. In this experiment, figures consisting of various sizes of lines or ellipses (ovals) are assigned numbers. You will first receive practice trials so that you can learn these number/figure assignments. Next the figures will be presented one at a time in random order and you must identify each figure by its assigned number. You will be asked to identify only one kind of figure at a time although you will see different sizes of each figure during the presentation.

ABSOLUTE MAGNITUDE ESTIMATION*: You will be shown on the computer screen various sizes of lines and ellipses (ovals). Your task is to judge each figure using a simple technique called absolute magnitude estimation. Essentially, you are to assign a number to each figure in such a way that your impression of how large the number is matches your subjective impression of how large the figure is. For example, a figure which seems moderately large should be assigned a number which you consider to be moderately large. Don't evaluate the figures in terms of physical units of measurement such as inches or centimeters, just judge your overall subjective impression. Simply match your impression of the subjective size of each figure with your impression of the size of the number you are considering. Don't worry about numbers assigned previous figures, just judge each one independent of the others. You may use any positive number which seems appropriate-- whole numbers, decimals or even fractions.

*Instructions were not read verbatim

APPENDIX B

ANALYSIS OF VARIANCE SUMMARY TABLES

Appendix B1. Analysis of variance summary table for information transmission measures.

Factors listed in the summary table are as follows:

Main Effects

AA: AJ vs AME (Scaling Paradigm)
BB: Line vs Ellipse (Figure)
CC: 4 vs 8 vs 12 Stimuli (Series)

Interactions

AA BB: Scaling X Figure
AA CC: Scaling X Series
BB CC: Figure X Series
AA BB CC: Scaling X Figure X Series

Scaling X Figure interaction not considered significant by adjusted F test, F(1.46, 32.16)=3.73, p=.05 (Kirk, 1982).

SOURCE	DF1/	DF2	F	P VALUE	MEAN SQUARE	SUM OF SQ
AA	1/	22	14.7961	.0009	2.0100	2.0100
BB	1/	22	23.0166	.0001	1.4238	1.4238
AA BB	1/	22	0.0850	.7733	0.0053	0.0053
CC	2/	44	127.6087	.0000	5.4882	10.9765
AA CC	2/	44	3.4470	.0407	0.1482	0.2965
BB CC	2/	44	2.1375	.1300	0.0575	0.1150
AA BB CC	2/	44	0.9207	.4058	0.0248	0.0495
AA SS	22				0.1358	2.9885
AA SS BB	22				0.0619	1.3609
AA SS CC	44				0.0430	1.8924
AA SS BB CC	44				0.0269	1.1836

Appendix B2. Analysis of variance summary table for equivocation measures.

Factors listed in the summary table are as follows:

Main Effects

AA: AJ vs AME (Scaling Paradigm)
BB: Line vs Ellipse (Figure)
CC: 4 vs 8 vs 12 Stimuli (Series)

Interactions

AA BB: Scaling X Figure
AA CC: Scaling X Series
BB CC: Figure X Series
AA BB CC: Scaling X Figure X Series

Scaling X Figure interaction considered not significant by adjusted F test, F(1.44, 31.68)=3.73, p=.05 (Kirk, 1982).

SOURCE	DF1/	DF2	F	P VALUE	MEAN SQUARE	SUM OF SQ
AA	1/	22	14.8224	.0009	2.0145	2.0145
BB	1/	22	23.0175	.0001	1.4205	1.4205
AA BB	1/	22	0.0817	.7777	0.0050	0.0050
CC	2/	44	240.2175	.0000	10.3188	20.6377
AA CC	2/	44	3.4660	.0400	0.1483	0.2978
BB CC	2/	44	2.1208	.1320	0.0569	0.1138
AA BB CC	2/	44	0.9197	.4062	0.0247	0.0493
AA SS	22				0.1359	2.9900
AA SS BB	22				0.0617	1.3577
AA SS CC	44				0.0430	1.8901
AA SS BB CC	44				0.0268	1.1801

Appendix B3. Analysis of variance summary table for ambiguity measures.

Factors listed in the summary table are as follows:

Main Effects

AA: AJ vs AME (Scaling Paradigm)

BB: Line vs Ellipse (Figure)

CC: 4 vs 8 vs 12 Stimuli (Series)

Interactions

AA BB: Scaling X Figure

AA CC: Scaling X Series

BB CC: Figure X Series

AA BB CC: Scaling X Figure X Series

Transformation required for homogeneity of variance;

New Data = LOG base 10 (Old Data + 1)

SOURCE	DF1/	DF2	F	P VALUE	MEAN SQUARE	SUM OF SQ
AA	1/	22	32.2080	0.0000	2.4052	2.4052
BB	1/	22	10.7636	.0034	0.1066	0.1066
AA BB	1/	22	0.1737	.6808	0.0017	0.0017
CC	2/	44	58.7080	.0000	0.3421	0.6842
AA CC	2/	44	8.4228	.0008	0.0491	0.0982
BB CC	2/	44	0.4346	.6503	0.0019	0.0037
AA BB CC	2/	44	2.1920	.1237	0.0094	0.0188
AA SS	22				0.0747	1.6429
AA SS BB	22				0.0099	0.2179
AA SS CC	44				0.0058	0.2564
AA SS BB CC	44				0.0043	0.1887

Appendix B4. Analysis of variance summary table for response alternatives.

Factors listed in the summary table are as follows:

Main Effects

AA: Line vs Ellipse (Figure)

BB: 4 vs 8 vs 12 Stimuli (Series)

Interactions

AA BB: Figure X Series

SOURCE	DF1/	DF2	F	P VALUE	MEAN SQUARE	SUM OF SQ
AA	1/	11	0.1285	.7268	28.1250	28.1250
BB	2/	22	16.1223	0.0000	3348.2222	6696.4444
AA BB	2/	22	0.6696	.5220	83.1667	166.3333
SS	11				2245.5896	24701.4861
SS AA	11				218.8826	2407.7083
SS BB	22				207.6768	4568.8889
SS AA BB	22				124.1970	2732.3333

END
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